Coulomb effects in four nucleon continuum states

R. Lazauskas[a] *, J. Carbonell[a]†.

[a]Laboratoire de Physique Subatomique et de Cosmologie, 53. avenue des Martyrs, 38026 Grenoble Cedex, France

The Faddeev-Yakubovski equations are solved in configuration space for low energy four-nucleon continuum states. Coulomb interaction was included into the formalism permitting an exact description of the scattering states in p+^{3}He and p+^{3}H systems.

Three- and four-nucleon systems are the testing ground for studying the nuclear interaction. If the modern NN potentials have reached a very high degree of accuracy in describing the two-nucleon data, they are unable to account for the binding energies of the lightest nuclei. The use of three-nucleon forces (3NF) is mandatory. By adjusting their parameters, one can obtain a satisfactory description of the nuclear bound states up to A=10 [1].

Low energy three-nucleon scattering observables are quite insensitive to 3NF effects. Furthermore, three-nucleon dynamics is relatively rigid once deuteron and triton binding energies are fixed. The four nucleon continuum states, containing sensible structures as thresholds and resonances, can show a stronger dependence on the interaction models [2].

We present in this contribution some results concerning low energy four-nucleon continuum states. Faddeev-Yakubovski equations have been modified to include Coulomb interactions and then solved in configuration space. The n-^{3}H, p-^{3}He and p-^{3}H systems have been investigated using MT I-III and several realistic NN potentials in conjunction with Urbana IX (UIX) 3NF. Our scattering length results are summarized in Table 1.

Table 1
4N scattering lengths calculated using different interaction models.

	MT I-III		Av. 14		Av. 18+UIX	
	$J^\pi = 0^+$	$J^\pi = 1^+$	$J^\pi = 0^+$	$J^\pi = 1^+$	$J^\pi = 0^+$	$J^\pi = 1^+$
n-^{3}H	4.10	3.63	4.28	3.81	4.04	3.60
p-^{3}He	11.5	9.20	-	-	-	-
p-^{3}H	-63.1	5.50	-13.9	5.77	-16.5	5.39

The first effort was devoted to describe the Coulomb-free n-^{3}H system. Semi-realistic MT I-III potential was shown to be very successful in describing the total as well as the

*e-mail: lazauskas@lpsc.in2p3.fr
†e-mail: carbonell@lpsc.in2p3.fr

differential cross sections [3]. In our recent calculations with realistic Av.14 and Av.18 potentials, we were able to considerably enlarge the partial wave basis (PWB) compared to [4]. Inspite of having some effect on the negative parity phase shifts, the total cross section near the resonance peak ($E_{cm} = 3\ MeV$) has not yet been improved (see Fig. 1). We should notice, however, that the 2^- phase shifts, the most relevant contribution due to its statistical factor, are not yet fully converged. By including UIX-3NF we have managed to reproduce the experimental zero-energy cross sections, which are overestimated by realistic NN interaction without 3NF, but their effect near the peak remains very small.

By including Coulomb interaction we were able to handle the n-^{3}H isospin partner: p-^{3}He. Yet calculations were done with MT I-III model only. The p-^{3}He scattering lengths predicted by this model (see Table 1) agree with experimental values and are very close to the ones obtained by the Pisa group [5], using Av.18+UIX forces. Like in the n-^{3}H case, MT I-III was found to be successful in describing differential cross sections up to d+p+p threshold [6].

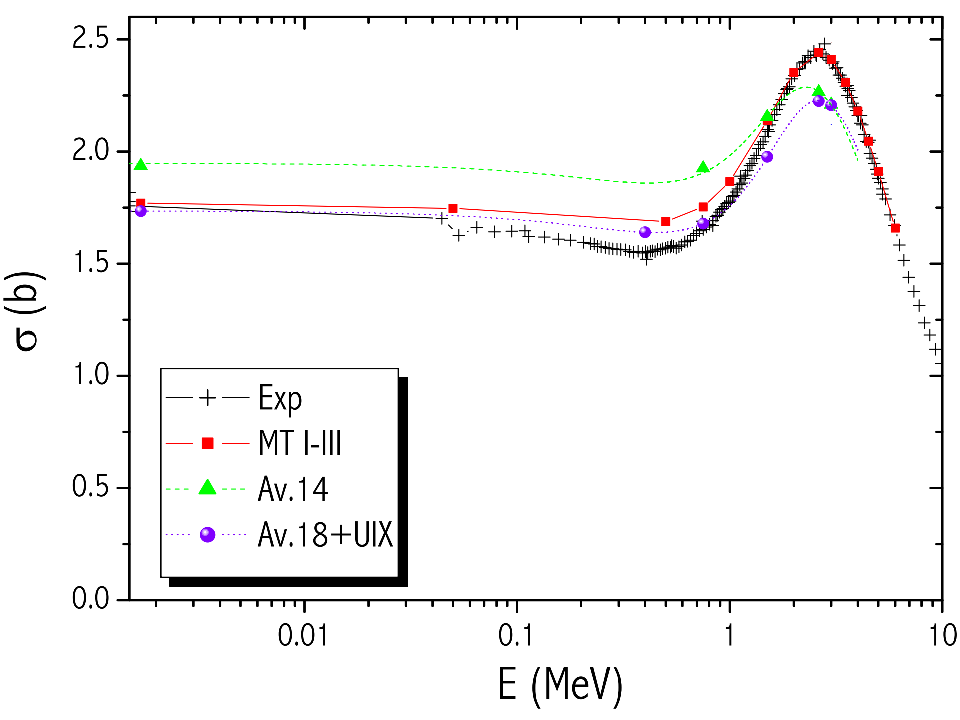

Figure 1. Calculated n+^{3}H total cross sections compared with experimental data [7].

The p-^{3}H scattering at energies below n-^{3}He threshold constitutes a challenging problem due to the existence of a J$^\pi$=0$^+$, ^{4}He virtual state in between. The richness of this system makes scattering observables very sensitive to the interaction and therefore provides an excellent test of NN potentials. The splitting of p-^{3}H and n-^{3}He thresholds is essentially due to Coulomb interactions. By properly taking them into account in our calculations, we have placed the ^{4}He virtual state in between the two thresholds. This is reflected by a negative 0^+ p-^{3}H scattering length. Note that in all the preceding works, where Coulomb interaction was neglected, the first ^{4}He excitation appeared as a bound state.

Unlike in the other 4N systems, MT I-III predictions for p-^{3}H scattering lengths as well as the excitation function – $\frac{d\sigma}{d\Omega}(E)\Big|_{\theta=120^\circ}$ – are in disagreement with experimental data. ^{4}He virtual state is located too close to the p-^{3}H threshold and has very small width.

Our calculations with realistic potentials are still limited in PWB. Nevertheless, they provide the very promissing results displayed in Fig. 2. Pure 2NF models predict too large singlet scattering length, thus placing the virtual state too far from the threshold. On the other hand by implementing UIX-3NF in conjunction with Av.18 NN model one obtains singlet scattering length as well as the excitation function $\frac{d\sigma}{d\Omega}(E)\Big|_{\theta=120^\circ}$ in agreement with experimental data [8]. A detailed analysis of these calculations is in progress [6,9] as well as their extension above the n-3He threshold.

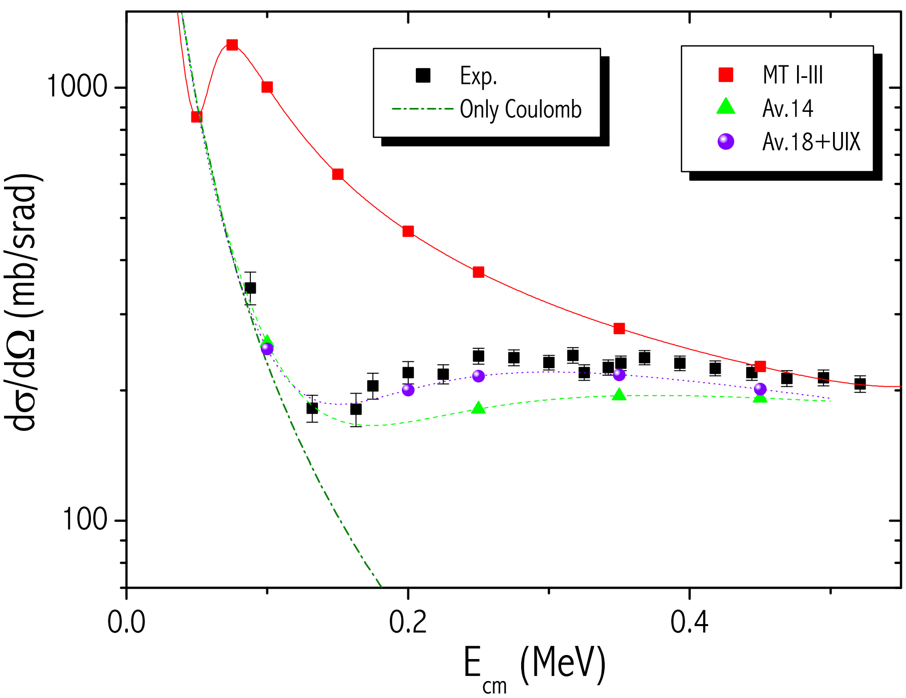

Figure 2. Energy dependence of p+^{3}He elastic differential cross sections at 120°: experimental results are compared with our calculation.

REFERENCES

1. S. Pieper et., Phys.Rev. **C66**, 044310 (2002).
2. A. C.Fonseca , Phys. Rev. Lett. **83**, 4021 (1999).
3. J. Carbonell, Few-Body Syst. Suppl. **12**, 439 (2000).
4. F.Ciesielski, J. Carbonell, C. Gignoux, Phys Lett. **B447**, 199 (1999).
5. M. Viviani, S. Rosati, A. Kievski, Phys. Rev. Lett. **81** 1580, (1998).
6. R. Lazauskas, PhD Thesis, Université Joseph Fourier, Grenoble (2003).
7. T.W. Phillips, B.L. Berman and J.D. Seagrave, Phys. Rev. **C22** 384 (1980).
8. N. Jarmie, M.G. Silbert, D.B. Smith, J.S. Loos, Phys. Rev. Rev. 130 5, (1963).
9. R. Lazauskas and J. Carbonell, to be published.